



U.S. Department
of Transportation
**Federal Aviation
Administration**

Advisory Circular

Subject: GUIDANCE MATERIAL FOR 14 CFR
§33.19, DURABILITY, FOR RECIPROCATING
ENGINE REDESIGNED PARTS.

Date:
Initiated By: ANE-110 **AC No:** 33.19-1[DRAFT]
Change:

1. **PURPOSE.** This advisory circular (AC) provides guidance and acceptable methods, but not the only methods, that may be used to demonstrate that redesigned parts for reciprocating engines comply with the requirements of §33.19 of Title 14 of the Code of Federal Regulations (14 CFR) or §13.104 of the Civil Air Regulations (CAR). This AC addresses type design changes, parts manufacturing approvals (PMA), and supplemental type certificates (STC) for critical, highly stressed, or complex parts in reciprocating engines. Like all AC material, this AC is not, in itself, mandatory and does not constitute a regulation. While these guidelines are not mandatory, they are derived from extensive Federal Aviation Administration (FAA) and industry experience in determining compliance with the pertinent regulations.

2. **RELATED REGULATIONS (CFR) AND READING MATERIAL.**

a. **Related Regulations.**

- (1) 14 CFR Part 21. Sections 21.33, 21.53, 21.101, 21.115, and 21.303.
- (2) 14 CFR Part 33. Sections 33.19, 33.43, 33.49, 33.53, 33.55, 33.57, and Appendix A.
- (3) CAR Part 13. Sections 13.21, 13.104, 13.151, 13.154, and 13.156.

b. **Orders and Policy.**

- (1) Engine and Propeller Directorate Policy, Durability Substantiation of Reciprocating Engine Redesigned Parts (PMA, STC, Type Design Change), dated November 29, 1999.
- (2) FAA Order 8110.42A, Parts Manufacturer Approval Procedures, dated March 31, 1999.

(3) FAA Order 8110.4B, Type Certification Process, dated April 24, 2000.

c. Industry Documents.

(1) “The Selection of Steel for Fatigue Resistance” from *ASM Metals Handbook*, Volume 1, 8th edition.

(2) “Aluminum Alloy Castings: Mechanical Properties” from *ASM Metals Handbook*, Volume 1, 8th edition.

(3) “Fatigue Resistance of Steels” from *ASM Metals Handbook*, Volume 1, 10th edition.

(4) “Fatigue Failures” from *ASM Metals Handbook*, Volume 10, 8th edition.

3. **APPLICABILITY**. This AC applies to PMA (test and computation), STC, or type design change certification projects involving critical, highly stressed, or complex parts on reciprocating engines. These parts are used on reciprocating engines certificated under part 33 and installed in aircraft certificated under parts 23, 27, and 29. This AC does not apply to PMA parts approved by the FAA as being identical to the corresponding engine type design part, as those parts are not considered redesigned.

SIGNATURE BLOCK

CHAPTER 1. INTRODUCTION

1-1. Background.

a. The initial models of today's horizontally-opposed piston engines were certified in the late 1940s and 1950s. These engines entered service with recommended time between overhaul (TBO) intervals of 500 hours to 750 hours. These TBOs were recommended by the engine designer and approved by the FAA based on the results of the certification block testing. Successful performance of the block testing was sufficient to substantiate safe operation over the recommended TBO because of the short duration of those initial TBOs, thus meeting the durability requirement of CAR §13.104. However, over the last 50 years advances in materials, manufacturing processes, and engineering analysis methods have enabled engine manufacturers to design more durable engines. This has allowed the manufacturers to gradually increase their recommended TBOs for existing engine designs to intervals up to 2000 hours. FAA approval of these TBO increases was based on successful service, engineering design, and test experience. New engine designs, however, are still introduced with relatively short TBOs, in the range of 600 hours to 1000 hours, with TBO extensions approved by the FAA after accumulation of successful service experience.

b. Reciprocating engine parts have historically been designed to operate with safety factors large enough to ensure that operating stress levels are significantly below their relevant fatigue strengths or endurance limits. Under normal operating conditions, these parts can then be expected to have extremely lengthy or infinite service lives. Critical parts in reciprocating engines are, therefore, not normally assigned finite service lives. This is in contrast to rotor structures in turbine engines, which typically have calculated service lives beyond which structural failures are expected.

(1) For turbine engines, these finite lives, along with the hazard to the aircraft in the event of a turbine rotor failure, require life limits for these turbine parts. These life limits are in turn designated as airworthiness limitations for the turbine engine model and are considered mandatory by the FAA.

(2) For reciprocating engines, the essentially infinite fatigue lives of critical parts, along with the reduced hazard to the aircraft in the event of their failure, make life limits and mandatory airworthiness limitations for these parts unnecessary. Instead, the reciprocating engine designer establishes recommended periodic engine inspection intervals, called TBOs, that are primarily intended to provide for the inspection and replacement of worn components. This does not, however, diminish the criticality of these parts. If essentially infinite life cannot be substantiated for a critical part in a reciprocating engine, then a unique service interval must be assigned to the part to require replacement before the fatigue life expires.

c. Over the life of an engine, redesigned parts are approved for incorporation into existing engine designs through type design changes, PMA, or STC. Redesigns can involve material changes, material process changes, geometry changes, or any combination of these. What may initially appear to be a relatively benign design change, such as a material process change, can

actually have a significant effect on material strength or stress and on the ability of the part to operate safely for the recommended engine TBO.

d. Replacement PMA parts approved under the identity guidelines are not considered redesigned parts. The certification data submitted to the FAA for these identical parts should substantiate that the part does not incorporate any design changes relative to the corresponding engine type design part. If this cannot be substantiated, then the part should be evaluated in accordance with the test and computation guidelines applicable to PMA parts.

e. The current regulations that apply to these design changes require that engine parts be designed to operate safely for the duration of the applicable overhaul interval. The applicable overhaul interval is either the recommended TBO for the engine on which the part will be installed or a TBO established specifically for the redesigned part. In cases in which applicants have recognized the effect of the lengthy TBOs on durability, they have performed tests and analyses specifically to meet the durability requirement. These tests and analyses typically substantiate extremely lengthy or essentially infinite fatigue lives. However, in other cases, the durability requirement has been substantiated solely by performance of the endurance test of §33.49 or CAR §13.254, despite the lengthy TBOs. The FAA has developed this AC to describe acceptable methods, but not the only methods, for showing compliance with the durability regulations.

1-2. Definitions.

a. Critical Parts. The FAA has applied the term “critical” to parts, appliances, characteristics, processes, maintenance procedures, or inspections that if failed, omitted, or non-conforming may cause significantly degraded airworthiness of the product during take-off, flight, or landing.

b. Fatigue Mechanism. Fatigue mechanism is the process by which a crack initiates and propagates in a part due to repeated loading.

c. Margin of Safety. The margin of safety is the ratio of excess strength to the nominal required strength in the design of a part.

d. Redesigned Parts. Redesigned parts are those parts for which material changes, material process changes, geometry changes, or any combination of changes have been incorporated into an existing approved design. FAA approval of these parts is accomplished through type design changes, PMA, or STC. Replacement PMA parts approved under the identity guidelines are not considered redesigned parts.

CHAPTER 2. GENERAL

2-1. Certification Procedures. The certification procedures in part 21 require redesigned parts to meet the applicable airworthiness standards.

a. For PMA (test and computation), §21.303(c)(4) requires the applicant to: “show that the design of the part meets the airworthiness requirements of the Federal Aviation Regulations applicable to the product on which the part is to be installed.”

b. For STC parts, §21.115(a) requires that the: “applicant for a supplemental type certificate must show that the altered product meets applicable airworthiness requirements.”

c. For type design changes, §21.101(a) requires that an applicant for a change to a type certificate must show that the changed product complies with the applicable airworthiness requirements.

2-2. Airworthiness Standards. For engine parts, the applicable regulations or airworthiness standards are contained in either part 33 or CAR part 13. The part 21 regulations referenced in paragraph 2-1 of this AC require an applicant to review the applicable airworthiness standards and determine which specific sections require re-evaluation based on the redesign of the part and the extent of that redesign. Critical, highly stressed, or complex parts in reciprocating engines, by their very nature, require re-evaluation of durability when redesigned.

a. CAR §13.2020, Durability, was issued in August 1941, before turbine engines were introduced in civil aviation. This regulation, therefore, was intended for reciprocating engines. The initial version of the durability requirement stated that: “The wearing surfaces, lubrication system and *parts subject to fatigue* shall be so designed and constructed that no unsafe condition will develop *between overhaul periods* when the engine is properly installed, operated and maintained in an aircraft” (emphasis added). The wording of this original version of the durability regulation establishes an unambiguous link between fatigue life and overhaul periods. The durability regulation was later moved to CAR §13.104 and revised to read: “all parts of the engine shall be designed and constructed to minimize the development of an unsafe condition of the engine between overhaul periods.”

b. CAR §13.104 is part of Subpart B, which addresses the design and construction of reciprocating engines. Therefore, §13.104 applies “to the engine when it is installed, operated, and maintained in accordance with the instruction manual,” as stated in CAR §13.100(b). Thus, the limits specified in the service instructions, including the TBO, must be consistent with the substantiated engine design.

c. The intent of CAR §13.104 was carried over to §33.19 when part 33 became effective on February 1, 1965. Section 33.19 still reads substantially the same as §13.104 regarding the durability of reciprocating engines, requiring the engine design to minimize the development of an unsafe condition between overhaul periods.

2-3. Durability Compliance. For PMA (test and computation), STC, or type design change certification projects involving critical, highly stressed, or complex parts in reciprocating engines, the following should be considered when substantiating compliance with §33.19 or CAR §13.104:

- a. The substantiation scope should be based on the extent of the redesign.
- b. The substantiation scope should reflect the TBO that applies to the engine on which the part will be installed, unless the applicant chooses to specify a separate inspection or replacement interval for the part. The applicant should perform testing and analysis sufficient to substantiate a fatigue life that is essentially infinite unless a fatigue life limit is defined for the part. In general, the length of the TBO or the extent of the redesign will determine the amount of testing and analysis that the applicant should perform.
- c. The substantiation scope should include material analyses and testing, finished part analysis and testing, and engine block testing. The scope will depend on the criticality of the component and the differences from the original type-certificated part.
- d. For parts for which a fatigue life limit has not been defined, the substantiation test methods should be designed to accumulate a sufficient number of significant fatigue cycles for substantiation of an extremely lengthy (essentially infinite) fatigue life. The test methods should also consider the duty cycle per flight of the applicable engine, extrapolated to the recommended TBO. Engine parameters, such as manifold pressure, horsepower, cylinder head temperature (CHT), exhaust gas temperature (EGT), and revolutions per minute (RPM), should be selected to simulate the most adverse fatigue loading conditions expected in service.

2-4. Conformity. The certification procedures specified in part 21 require that parts undergoing certification testing be shown to conform to their type design. This conformity requirement encompasses all aspects of the type design, including manufacturing and assembly processes, material specifications, and finished part conformity. The specific regulations are:

- a. Section 21.303(e), (e)(1), and §21.303(f)(2) through (f)(4) specify conformity requirements for PMA parts. They require the applicant to demonstrate that the materials, part design, and processes, construction, and assembly conform to the design and authorize the Administrator to make any inspection necessary to determine compliance with these requirements.
- b. Sections 21.33 and 21.53 specify conformity requirements for STC and type design change projects.

2-5. Additional Installation Approvals. Engine designers occasionally use parts with common part numbers on several different engine models. For PMA applications for this type of common part, paragraph 9(g)(4) of FAA Order 8110.42A requires the Aircraft Certification Office (ACO) reviewing the application to separately evaluate the installation eligibility of the part for each engine model. FAA approval will be based upon a determination that each engine model will continue to comply with the applicable airworthiness regulations with the PMA replacement part

installed. As discussed throughout this AC, the applicable airworthiness regulations include a requirement that the applicant demonstrate the durability of the part, which would require that the common part operate safely between overhaul intervals for each of the engine models on which it is proposed to be installed. Testing should be performed on each engine model, unless it can be shown that the installed environment (stress, temperature, etc.) of the engine model for which the applicant applies for eligibility is less severe than a model for which the part has previously been tested and approved. This can be done with an analysis that provides a quantitative comparison of the installed environments in terms of the relevant engine operating parameters.

2-6. Substantiation Guidance. This AC provides the following information for defining substantiation plans to show compliance with §33.19 or CAR §13.104 for redesigned, critical, highly stressed, complex, or other significant reciprocating engine parts.

- a. An overview of those internal parts of reciprocating engines whose failure could impact safe operation of the engine.
- b. Recommended substantiation methods, including conformity, test, and analyses.
- c. An appendix that provides an overview of potential process deficiencies of reciprocating engine internal parts, including factors that may affect stress and strength.
- d. An appendix that provides information regarding the assessment of the strength of materials used to manufacture critical parts.

CHAPTER 3. CRITICAL PARTS

3-1. Background. The FAA has applied the term “critical” to parts, appliances, characteristics, processes, maintenance procedures, or inspections that if failed, omitted, or non-conforming may cause significantly degraded airworthiness of the product during take-off, flight, or landing (see FAA Order 8110.42A, section 6.c.). All parts of the engine are required to undergo durability evaluation during certification, but special emphasis should be placed on critical parts due to the potential impact of these parts on flight safety.

a. While many parts on reciprocating engines can be designated as critical, a comprehensive and thorough durability evaluation is especially important for critical engine parts that are also exposed to high stress levels or temperatures. This durability evaluation will confirm that these parts have adequate margins in their design to accommodate variations in material properties and manufacturing processes, lengthy inspection intervals, and material strength degradation due to exposure to wear and corrosive environments.

b. The following reciprocating engine parts have been known to experience high stress levels combined (in some cases) with high temperatures and have been considered critical parts by the FAA. This list should be considered representative, but not all-inclusive, of a typical horizontally-opposed, spark ignition, reciprocating engine. However, the determination of the criticality of any specific part depends on the design of the part and the associated engine and should not be limited to those parts specified in the following list. Additional details concerning these parts may be found in Appendix 3 of this AC.

- (1) Crankshafts.
- (2) Counterweights.
- (3) Connecting Rods.
- (4) Connecting Rod Bolts.
- (5) Pistons.
- (6) Piston Pins.
- (7) Propeller Drive Gears.
- (8) Cam/Crank Gears and Associated Idler Gears.
- (9) Magneto/Ignition System & Ancillary Drive Gears.
- (10) Gear Attachment Bolts.
- (11) Driveline Quill Shafts.

- (12) Cylinder Heads.
- (13) Cylinder Barrels.
- (14) Rocker Arms, Rocker Shafts and Bolts, if they are the primary means of attachment.
- (15) Valve Push Rods.
- (16) Intake Valves.
- (17) Exhaust Valves.
- (18) Valve Spring Retainers and Keepers.
- (19) Camshafts.
- (20) Crankcases.
- (21) Crankcase Through Bolts and Cylinder Deck Studs.
- (22) Engine Mounts/Mount Leg Brackets/Attachment Bolts (potential loss of control).
- (23) Exhaust System Tubes (potential fire risk).
- (24) Exhaust System Band Clamps and Connectors (potential fire risk).
- (25) Connecting Rod and Crankshaft Main Bearing Inserts.

CHAPTER 4. COMPLIANCE METHODS

4-1. General. Compliance methods for critical components should encompass both analysis and test of the uninstalled component, along with engine testing of the installed component.

Regardless of the type of certification test, component, or complete engine, FAA conformity is required before the testing.

4-2. Conformity.

a. The high stress levels (and high temperatures for certain parts) at which critical parts frequently operate make these components sensitive to variations in material properties and manufacturing processes. Control of these properties and processes is necessary to ensure the fatigue tolerance meets the intent of the design. In addition, the validity of the certification tests depends on adherence to the type design during the manufacture of the test hardware. The type design includes the material properties, manufacturing processes, assembly procedures, and physical part design characteristics. FAA conformity requirements are intended to address these issues.

b. A conformity plan should be developed for the certification test hardware. The plan should provide for conformity of all phases of manufacture of the specific part(s) to undergo certification testing. FAA conformity requirements will be established by the cognizant FAA ACO. This requires advance planning and coordinating by both the applicant and the FAA for conformity of the initial stages of test hardware fabrication, such as the forging or casting processes. Chapter 5-2 of Order 8110.4B contains an overview of the process the FAA uses to evaluate demonstrations of conformity. In general, a conformity plan should include the following elements:

(1) Evaluation of the process methods and controls (such as forging, casting, machining, and surface finishing processes) that were used during all phases of manufacturing the certification test article;

(2) Evaluation of in-process assembly procedures used to assemble the test article;

(3) Observation of in-process functional tests performed during all phases of manufacture of the test article;

(4) Verification of the design characteristics of the finished part;

(5) Verification of the certification test installation; and

(6) Observation of the certification tests.

4-3. Component Analysis and Test. The estimation of margins of safety is recommended for redesigned critical parts. It is also particularly useful for future redesigns and service problem resolution. The safety margins may be estimated by stress and strength computations,

supplemented (in many cases) by bench testing the uninstalled components. See Appendix 3 for additional details. The laboratory determination of component stress and strength on actual finished components provides data that is more accurate than that obtained by calculation or by using handbook material values, thereby giving more precise estimates of safety margins. The results of these analyses should be validated by testing of the part while installed in an engine. Appendix 1 provides information about potential process deficiencies that can impact the strength of a part or the applied stress on the part.

a. **Material Strength Evaluation.** The evaluation of material strength should not rely exclusively on material reference data from textbooks and industry documents (see Appendix 2). Testing and metallographic inspection of the finished part, or partially finished part (forging, casting, etc.) should be performed to evaluate dimensional and material properties and to confirm that the specified manufacturing processes are adequate and have been performed properly. Component strength can be evaluated by the following inspections, evaluations, and determinations, as applicable (see Appendix 2 for notes relative to these items):

- (1) Dimensional and surface finish inspections.
- (2) Crack and defect inspections, using magnetic particle inspection (MPI), ultrasonic inspection (U/T) or fluorescent penetrant inspection (FPI), or other methods acceptable to the Administrator.
- (3) Porosity inspection of castings, using radiography and applicable reference standards.
- (4) Evaluation of the quality of corrosion-resistant surface treatments, particularly painting and plating.
- (5) Evaluation of the quality of surface cold working operations, particularly shot-peening.
- (6) Material chemistry (typically obtained from material supplier certificates).
- (7) Material hardness, including surface and internal hardness and also the case/core hardness profile of nitrided, induction-hardened or carburized steel components for case depth determination.
- (8) Metallographic inspections, which provide data on material microstructure and macrostructure, including grain structure, grain boundary anomalies, porosity, and inclusions.
- (9) Experimental determination of tensile, yield, and fatigue strength, when possible.

b. **Stress Analysis.**

- (1) Component stress levels, along with material strength, should be used to determine margins of safety.

(2) Knowledge of assembly and operating stress levels is a valuable asset regarding the structural aspects of component development, particularly during redesign or optimization of an existing design. Stress analysis procedures should be used to resolve service difficulties involving component cracking. Without reliable stress data, structural design evaluation is extremely difficult.

(3) Depending on the component being evaluated, the analysis may consist of theoretical or experimental methods, or a combination of these methods.

(a) Theoretical. Theoretical methods include basic calculations for components with relatively simple configuration and finite element modeling for more complex components. Finite element modeling should be correlated to actual test data to ensure accuracy.

(b) Experimental. These stress analysis techniques commonly include laboratory bench testing of components. They typically rely on the use of strain gauges, supplemented by brittle lacquers and photo-elastic coatings. The most useful data is obtained when strain gauges or coatings are placed in areas of known high stress, such as fillet radii or in locations where service cracking has occurred. However, strain gauges and surface coatings can only be used on surfaces that are directly accessible. Internal or hidden surfaces (in joints, for example) require theoretical studies for stress evaluation. Dynamic measurements of the stress levels on many critical components should be obtained by using strain gauges installed on operating engines (usually in test cells).

4-4. Engine Testing Methods.

a. General. Engine durability testing to substantiate compliance with §33.19 should be based on the fatigue characteristics of the part, the duty cycle of the engine, and the applicable overhaul or inspection interval. The engine test guidelines provided in this section may be used for durability testing of critical parts. The test guidelines are based on the following factors:

(1) Fatigue Mechanism. Test guidelines were developed for each of the primary fatigue mechanisms affecting typical critical parts installed in a reciprocating engine. Typically, reciprocating engine critical part failure can be attributed to fatigue overload resulting from a large number of stress cycles at a low level of overstress; this is referred to as “high cycle fatigue” (HCF). Depending on its design and function, a critical part may be most affected by either:

- (a) A forced vibratory response;
- (b) A forced vibratory response in combination with a resonant vibratory response; or
- (c) A forced vibratory response at high structural temperatures.

(2) Test Duration. The test guidelines have been designed to expose the critical parts to at least 10 million significant stress cycles under the loading conditions representative of the

relevant fatigue mechanism. This criterion is based on the fatigue strength characteristics of steel and cast aluminum. For steel parts, if fatigue cracking has not initiated within 10 million stress cycles, then they will most likely last indefinitely as long as the stress levels do not exceed the endurance limit. Cast aluminum parts also exhibit a reduction of fatigue strength above 10 million cycles. In addition, to allow for variations (or scatter) in the actual strengths of production components and differences between test and service operating conditions, a safety margin has been added that results in a total test duration greater than 10 million significant stress cycles. The test durations are also designed to represent the effect of the maximum stress cycles on the fatigue life of a part over a typical TBO range of approximately 2000 hours.

b. Test Guidelines. The three test guidelines described in this paragraph are comprised of unique durability tests in combination with certification block tests. Performance of the certification block tests will demonstrate partial compliance to the durability requirement (§33.19) and full compliance to the regulation associated with the particular block test (for example, §§33.43 or 33.49).

(1) HCF Forced Response Test. These tests are designed for critical parts whose primary fatigue mechanism is a forced vibratory response that is proportional to combustion pressures and inertia loads. The operating condition most associated with this type of fatigue mechanism is maximum power operation. High operating temperatures do not significantly affect the fatigue strength of this group of parts. These tests are identified as Type 1 tests in Appendix 3.

(a) Applicable Parts. The reciprocating engine critical parts typically found to be most susceptible to this fatigue mechanism include such parts as connecting rods, connecting rod bolts, piston pins, rocker arms, rocker shaft attachment bolts/studs, intake valves, and cylinder barrels (see Appendix 3 for a complete listing). The Type 1 tests may also be appropriate for other parts depending on the specific characteristics of the engine and part design.

(b) Test Guidelines. Type 1 tests include both the 150 hour endurance test of §33.49 and a unique durability test. The unique durability test should consist of operation for 100 hours at take-off power with normal CHT and EGT, plus operation for 50 hours at cruise power with normal temperatures.

(2) HCF Forced Response Plus Resonant Response Test. These tests are designed for critical parts whose primary fatigue mechanism is a forced vibratory response in combination with a resonant vibratory response that occurs at any engine speed at which the natural frequency of the part (or assembly that includes the part) coincides with the frequency of a combustion or inertia harmonic. The engine speed at which a component experiences resonant vibration depends on its physical design and the imposed dynamic conditions resulting from engine operation. The part can be excited in a torsional mode (for example, crankshafts) or a bending mode (for example, brackets). These resonances should be addressed by endurance testing at the engine speed and power condition that produces the peak resultant resonant stress level. Refer to §33.43 (b) and CAR §13.151. High operating temperatures do not significantly affect the fatigue strength of this group of parts. These tests are identified as Type 2 tests in Appendix 3.

(a) Applicable Parts. The reciprocating engine critical parts typically found to be most susceptible to this fatigue mechanism include such parts as crankshafts, propeller drive gears, main internal and magneto gears (see Appendix 3 for a complete listing). The Type 2 tests may also be appropriate for other parts depending on the specific characteristics of the engine and part design.

(b) Test Guidelines. Type 2 includes three tests: the 150 hour endurance test of §33.49, the vibration test of §33.43, and a unique durability test. The unique durability test should consist of operation for 100 hours at take-off power with normal CHT and EGT, plus operation for 50 hours at cruise power with normal temperatures. The vibration test should consist of operation for at least 10 million cycles at peak torsional resonance conditions (see §33.43). A typical torsional resonant frequency for a straight drive six-cylinder engine is around 200 Hz, which translates into a durability test time of about 14 hours at the RPM at which this resonant frequency occurs.

(3) HCF Forced Response Plus Temperature Test. These tests are designed for critical parts whose primary fatigue mechanism is a forced vibratory response at any engine power level whose effect on fatigue strength is aggravated by high structural temperatures. The operating conditions most associated with this type of fatigue mechanism include both take-off and cruise power conditions. During take-off and climb, maximum CHT is usually experienced because the cooling airflow through the cowling is reduced due to the “nose up” angle of attack and slower airspeed of the airplane. During cruise operation, maximum EGT and turbine inlet temperature (TIT) usually occur because the fuel/air ratio mixture setting is leaned to improve fuel economy. For engine bearings, high oil temperatures are also of concern, especially at high power. These tests are identified as Type 3 tests in Appendix 3.

(a) Applicable Parts. The reciprocating engine critical parts typically found to be most susceptible to this fatigue mechanism are pistons, exhaust valves, cylinder heads, exhaust system tubes, and exhaust system band clamps and connectors (see Appendix 3 for a complete listing). The Type 3 tests may also be appropriate for other parts depending on the specific characteristics of the engine and part design.

(b) Test Guidelines. Type 3 tests include both the 150 hour endurance test of §33.49 and a unique durability test. The unique durability test should consist of two segments. The first segment should include 100 hours at take-off power with fuel flow at the full rich limit specified by the engine manufacturer and with CHT and oil temperature controlled to the requirements of §33.49(a). The second segment should include 150 hours at the maximum cruise power recommended by the engine manufacturer with fuel flow leaned to produce the maximum allowable EGT (or TIT for turbocharged engines).

c. Similarity to Type Design Part. The above test guidelines should be adjusted based on the similarity of the redesigned critical part to the type design part or other similar parts manufactured by the designer. Parts with identical geometry and processes that can be substantiated as similar may be subjected to shorter test intervals than those described in this AC. However, in all cases, the part should be tested to a minimum of 10 million stress cycles at each

of the most adverse test conditions. For any critical part that exhibits differences in geometry, significant differences in material or manufacturing processes, or any uncertainty regarding the material or manufacturing process, the testing should follow the guidelines described in this AC.

4-5. Pass/Fail Inspection Criteria.

a. Pass/Fail. Following completion of the durability test, each component being evaluated should be subjected to crack inspections in addition to the normal wear/distortion measurements. The basic pass/fail criteria should be that each part is in good serviceable condition. That is, the part should still be able to perform its intended function with no imminent danger of engine performance degradation or flight hazard. Therefore, any abnormality such as cracking or unusual wear/distortion (significantly outside service limits) should generally result in a reevaluation of the design of the part. One possible exception is cracks that are classed as superficial, meet the engine manufacturer's service requirements for continued use, and have also been shown by service history not to result in flight safety issues. Cooling fins on cast aluminum cylinder heads (not barrels) are an example of an area in which cracking may be acceptable on some designs.

b. Inspections. The following inspections are commonly used for crack detection and should be standard practice. The actual technique used depends on the component being examined:

- (1) Magnetic Particle Inspection (MPI) for magnetic components.
- (2) Fluorescent Penetrant Inspection (FPI) for non-magnetic components.
- (3) Ultrasonic Inspection (U/T) for crankshafts, as specified by the engine manufacturer.
- (4) X-ray radiography.

c. Inspection of Interfacing Engine Parts. Other engine parts that are adjacent to, connected to, or functionally related to the redesigned part should be examined for any signs of structural failure or unusual wear. This ensures that the redesigned part does not have an adverse derivative affect on other engine parts.

d. Component Structural Complexity Issues. Cracking may not be readily detectable on parts with a complex assembly or shape. In such parts, a crack may only become apparent when it is well-developed, potentially when developed to the point of total component failure.

- (1) The following critical components have complex shapes or assemblies:

(a) Piston pins. These components are considered complex due to the hidden inner surface in some designs.

(b) Cylinder assemblies. These assemblies are considered complex due to the various hidden surfaces and also due to the poor visibility in small radius fin roots on both head and barrel.

(2) These components should be sectioned before MPI or FPI as follows:

(a) Piston pins. Section piston pins lengthwise along a diameter to expose the inner surface.

(b) Cylinder assemblies.

1. Remove the cylinder fins and inspect the fin root areas for cracking.

2. Remove valve seats, valve guides, and rocker arm shaft bushings (if so-equipped) and inspect the surfaces behind these parts.

3. Section cylinder assemblies lengthwise by making two cuts along diameters at right angles to expose threaded joint surfaces, edges of fin roots, and port interiors.

4-6. Other Methods of Durability Substantiation. This AC provides methods, but not the only methods, of compliance with the durability requirement. Other methods that could be used in place of some or all of the testing described in this AC include the following:

a. Accelerated or “lead the fleet” flight-testing to rapidly accumulate operating hours in advance of introducing the part to service.

b. Extensive experimental bench testing of the part to evaluate the material strength.

c. Finite element analysis to evaluate applied loads on the part. This type of analysis should be correlated and validated with testing or service experience with a similar part.

APPENDIX 1. POTENTIAL PROCESS DEFICIENCIES

A1-1. General.

a. The durability of a critical part depends on the design of that part and is a function of how that design accommodates the stress levels that result from the applied operating loads. Design elements such as geometry, material strength, resistance to wear and corrosion, and the difficulty of inspection in an assembled engine can all impact the part's durability over its inspection interval. Critical parts typically have small margins of safety that result from operation at high stress levels relative to their material strength. When redesigning these parts, this margin of safety can be reduced due to deficiencies in the processes used to manufacture the part. These potential process deficiencies fall into two main groups:

(1) Deficiencies that cause a local increase in stress (such as cracks, nicks, gouges, laps, rough surfaces, thin sections, undersize fillet radii, coarse porosity, and gross inclusions).

(2) Deficiencies that cause reductions in strength, wear resistance, or corrosion resistance (such as coarse microstructure, low hardness, improper heat treatments, and improper surface treatments).

b. The precise effects of process variations are difficult to quantify in terms of stress or strength. In addition, many deficiencies are difficult to detect or evaluate by analytical methods. For these and other reasons (related to dimensional and operational variables), substantial reliance should be placed on representative durability testing during certification of critical engine components.

c. These factors should also be considered when the extent of the redesign is limited to a change in material.

A1-2. Factors Affecting Stress and Strength. As stated previously, safety factors for most critical components are relatively small; component design implies a fairly precise knowledge of the levels of stress (due to assembly and operation) and the component strengths. Factors that either increase stress or reduce strength can therefore adversely affect the durability of these components due to the reduction in the margin of safety. A number of such factors can result from part redesign or from manufacturing processes.

a. Factors That Increase Stress. The following factors may affect mean (steady state) stresses and operational (dynamic) stresses:

(1) Surface treatment processes (such as carburizing, nitriding, and shot peening) that introduce beneficial surface stresses may also cause increased residual tensile stresses in the core. This can be especially significant in thin sections of parts.

(2) Prestress in bolted joints, which is generally beneficial if it is not excessive.

(3) Straightening, which can result in residual stresses and risk of cracking.

(4) Welding or brazing, which can cause residual stresses.

(5) Dimensional changes.

(6) Interference fits (assembly stresses).

(7) Reduced cross-sectional areas, including wall thicknesses, which can cause increased operational stresses and mean stresses.

(8) Manufacturing-related stress raisers, which can cause increased operational stresses. Surface stress raisers should normally be discovered during routine examination of each component by visual observation and crack inspection procedures. Subsurface stress raisers and deficiencies resulting in material strength issues are largely controlled by process definition and control, supported by destructive sampling procedures. Manufacturing related stress raisers include the following:

(a) Nicks, deep scratches, and gouges;

(b) Gross porosity, large inclusions, cold shuts, and hot tears (castings);

(c) Laps and inclusions (forgings);

(d) Sharp edges;

(e) Corrosion pits;

(f) Cracks;

(g) Overly rough surface finishes; and

(h) Undersize fillet radii.

b. Factors That Reduce Strength. Most of the following factors are especially significant in their effect on fatigue strength, a major design consideration for reciprocating engine components.

(1) Low hardness (specifically true for steels; less significant for cast aluminum alloys). Low hardness is commonly the result of improperly performed heat treatment processes.

(2) Coarse microstructure/grain size, adversely affecting static strength, fatigue strength, and toughness. Coarse microstructure/grain size is commonly the result of excessive

temperatures during casting and forging operations or improperly performed normalizing (for steels) and heat treatment processes.

(3) Excessive impurities, inclusions, or porosity (castings).

(4) Decarburization of steel surfaces, causing a soft, low-strength surface layer.

Decarburization of steel surfaces is typically associated with high temperature during forging operations; some decarburization may be acceptable.

(5) Improperly performed surface treatments such as carburizing, nitriding, and shot peening.

(6) Improperly performed plating treatments of high strength steels, resulting in hydrogen embrittlement.

(7) Improperly performed joining processes such as welding or brazing, which exhibit incomplete fill or, in the case of welding, local section reduction.

APPENDIX 2. NOTES ON MATERIAL STRENGTH EVALUATION

A2-1. Metallographic Analysis. In combination with chemistry and hardness data, metallographic analysis is a fundamental tool for assessing critical component material properties. The metallographic inspection may be expected to provide information of a basic microstructural nature, including grain structure, the presence or absence of unusual intergranular conditions, porosity, and inclusions in the area sectioned. However, there are limits to the amount of information that can be obtained during a general metallographic evaluation. The information gathered depends on the scope of the evaluation. Component idiosyncrasies may go undetected without a thorough understanding of the manufacturing processes. Changes in microstructure between “good” and “bad” material performance are sometimes so subtle as to be indistinguishable.

A2-2. Microstructural Analysis. There are several important characteristics that a general microstructural evaluation may miss or, if detected, may not thoroughly assess in terms of component strength. The following list represents examples of several areas of analytical difficulties:

- a. Detection of hydrogen embrittlement.
- b. Detection of non-homogeneous microstructure.
- c. Evaluation of directional properties.
- d. Effects of section thickness on the properties of low alloy, high hardenability steels.
- e. Detection of local nitrided surface case depth reduction (resulting from grinding/overpolishing).
- f. Evaluation of decarburized layer thickness in terms of its effect on the fatigue strength of forged steel components.
- g. Evaluation of cast aluminum microstructural and macrostructural variations and their effects on component fatigue strength.

A2-3. Material Strength Reference Data.

- a. A large amount of basic material strength data is available in reference books. Although very valuable, the data, especially that on fatigue strength, should be used cautiously. Reports published in the handbooks of the American Society for Metals (ASM) indicate that there are significant problems in establishing or confirming fatigue strengths by relying on reference data. “The Selection of Steel for Fatigue Resistance” reports that although the fatigue strength of steel is usually in proportion to the tensile strength, this generalization does not hold in many instances and is not true over wide ranges of tensile strength. “Aluminum Alloy Castings: Mechanical Properties” states that the fatigue strength of cast aluminum is markedly dependent on the casting

process. It further states that actual fatigue testing of fully machined cast aluminum parts is the only method of alloy or process selection. “Fatigue Resistance of Steels” states that: “Fatigue tests performed on small specimens are not sufficient for precisely establishing the fatigue life of a part.” “Fatigue Failures” discusses fatigue failures and prediction of fatigue life and includes many of the variables affecting fatigue life. It also identifies that standard fatigue life data (as normally presented in reference books) is usually based on the median life of the specimens tested. In addition, it refers to the significant scatter associated with such fatigue life values.

b. Nevertheless, estimates of basic material fatigue strength should be an essential part of the design or redesign processes; laboratory-derived fatigue data should be used to support this evaluation. When calculating safety factors, avoid overestimating fatigue strengths. The values used should reflect the lower limits of data scatter, rather than median values, when possible. The fatigue test data presented in curves in the *ASM Metals Handbook* reports is valuable for assessing alloy steel and cast aluminum fatigue strength scatter. Fatigue strength estimates should also include the effects of such parameters as mean stresses, stress concentrations, surface finishes, and structural temperatures.

c. Complex components, such as cylinder assemblies, that depend significantly on assembly procedures for their strength present an additional difficulty in estimating fatigue strengths (or lives). The durability of such assemblies cannot be fully evaluated based only on their individual component material properties. Due to uncertainties and operational variables that may affect stress and strength, critical component analysis should be supported by durability testing.

APPENDIX 3. CRITICAL COMPONENTS SUMMARY

COMPONENTS	FORCED VIBRATORY RESPONSE?	RESONANT VIBRATORY RESPONSE?	DURABILITY AFFECTED BY OPERATING TEMPS?	SUGGESTED BENCH TESTS FOR UNINSTALLED COMPONENTS	DURABILITY TESTS (See notes in Appendix 4)
Counterweights	Yes	No	No	None	Type 1
Connecting Rods	Yes	No	No	Exp. Stress Survey	Type 1
Connecting Rod Bolts	Yes	No	No	Tensile & Torque	Type 1
Piston Pins	Yes	No	No	Exp. Stress Survey	Type 1
Cylinder Barrels	Yes	No	No	Exp. Stress Survey	Type 1
Rocker Arms & Shafts (& Attach. Bolts*)	Yes	No	No	Exp. Stress Survey for Rockers	Type 1
Valve Push Rods	Yes	No	No	Compression	Type 1
Intake Valves	Yes	No	No	None	Type 1
Valve Spring Retainers and Keepers	Yes	No	No	None	Type 1
Camshafts	Yes	No	No	None	Type 1
Crankcases	Yes	No	No	Exp. Stress Survey	Type 1
C/case Through Bolts & Cyl. Deck Studs	Yes	No	No	Tensile & Torque	Type 1
Engine Mounts & Mount Leg Brackets	Yes	Yes***	No	Per CFR part 23 Subpart C - Struct.	Type 1
Crankshafts	Yes	Yes**	No	Exp. Stress Survey	Type 2
Propeller Drive Gears	Yes	Yes**	No	None	Type 2
Cam/Crank Gears and Associated Idler Gears	Yes	Yes**	No	None	Type 2
Magneto/Ignition System & Ancillary Drive Gears	Yes	Yes**	No	None	Type 2
Gear Attach. Bolts	Yes	Yes**	No	Tensile & Torque	Type 2
Driveline Quill Shafts	Yes	Yes**	No	None	Type 2
Pistons	Yes	No	Yes	Exp. Stress Survey	Type 3
Cylinder Heads	Yes	No	Yes	Exp. Stress Survey	Type 3
Exhaust Valves	Yes	No	Yes	None	Type 3
Exhaust System Tubes	Yes	No	Yes	None	Type 3
Exhaust System Band Clamps & Connectors	Yes	No	Yes	None	Type 3
Connecting Rod and Crankshaft Main Bearing Inserts	Yes	No	Yes****	None	Type 3 (max. oil temps. only)

* If the bolts are the primary means of attachment.

** The crankshafts, gears, quill shafts and gear attachment bolts are not themselves resonant, but form part of the engine/propeller torsional system and are therefore sensitive to resonant torsional activity.

*** Mount leg brackets may respond to engine rolling resonances during start up and shut down.

**** The durability of connecting rod and crankshaft main bearing inserts may be adversely affected by high oil temperatures, resulting in reduced fatigue strength and oil film thicknesses.

APPENDIX 4. DURABILITY TEST NOTES

In addition to the standard §33.49 endurance test, the durability tests listed in the Appendix 3 should also be conducted. The tests will result in a minimum of ten million stress cycles at each of the most adverse operating conditions, assuming four stroke operation and a typical take-off speed of 2700 RPM and a typical cruise speed of 2400 RPM. If actual operating speeds are significantly higher or lower than these values, some adjustments to the durability test hours may be appropriate.

The unique tests are defined as follows:

- **Type 1:** 100 hours at take-off power and 50 hours at cruise power with CHT and EGT (or TIT) in their normal operating ranges
- **Type 2:** Same as Type 1 with the addition of at least ten million stress cycles at peak torsional resonance conditions per §33.43.
- **Type 3:** 100 hours at take-off power with fuel flows at the full rich limit specified by the engine manufacturer, with CHT and oil temperatures controlled to the requirements of §33.49(a). In addition, the component(s) must be subjected to 150 hours at the maximum cruise power recommended by the engine manufacturer, with fuel flows leaned to produce the maximum allowable EGT (or TIT for turbocharged engines).

